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Stremmer then states: *“Thus those spectral components at the higher frequencies are emphasized ---- a general consequence of a differentiator.”*

In Stremmer's discussion, the result of Equation 6.107 is then applied to the case where white noise is applied to the discriminator input. This point must be emphasized. The dependence of the discriminator output on the square of frequency offset is established first. This result is then applied to the situation in which white noise is applied to the discriminator input. CUBE's assertion that the discriminator response is proportional to the square of frequency offset is somehow dependent on a white noise distribution at the input is therefore wrong.

If the input to the discriminator is white noise, then the input noise PSD is independent of frequency (ω), and:

$$S_{ns}(\omega) = N$$

Inserting this result into Equation 6.107 of Stremmer yields:

$$S_{no}(\omega) = \frac{1}{A} \omega^2 N$$

The preceding discussion is entirely consistent with the description of this topic in the Intersil submission to OET. The discussion presented in the Intersil analysis [1] begins by describing the effect of white noise on the discriminator output. The discussion then goes on to explain that the interaction between white noise and a desired signal is closely related to the interaction of a desired signal and a narrowband interfering signal. The interaction of the desired and a narrowband interfering signal is then described in more detail in the subsequent sections. This is clearly explained in the following excerpt from the Intersil paper:

“It can be shown that the noise spectral density (S_n) at the output of an FM demodulator is proportional to the square of frequency offset (f):

$$S_n = (N_0/A_c^2) f^2 \quad (4)$$

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where N_0 = noise density

A_c = Signal Power

In this case, both A_c and N_0 are constants. Therefore the S_n is entirely dependent on frequency offset (f) as shown in Figure 5.1-1. The interaction of noise and a signal in an FM system is closely related to the interaction of a desired signal (S) and an interfering signal (I) ... "

2.8.1.3 FM Discriminator Response to Offset Frequencies (Padgett)

The following analysis of the effects of interference at the input of an FM discriminator is provided by Jay Padgett (formerly of Lucent Technologies, now with Telcordia Technologies):

Consider two CW signals separated by radian frequency ω_Δ :

$$\begin{aligned} s_1(t) &= A \cos(\omega_c t + \phi_1) \\ s_2(t) &= \rho A \cos[(\omega_c + \omega_\Delta)t + \phi_2] \end{aligned} \quad (1)$$

where it is assumed that $\rho < 1$.

A received signal which is the sum of these two components can be expressed as:

$$\begin{aligned} r(t) &= s_1(t) + s_2(t) \\ &= \text{Re} \left\{ A \left[e^{j(\omega_c t + \phi_1)} + \rho e^{j[(\omega_c + \omega_\Delta)t + \phi_2]} \right] \right\} \\ &= \text{Re} \left\{ A e^{j(\omega_c t + \phi_1)} \left[1 + \rho e^{j(\omega_\Delta t + \phi_2 - \phi_1)} \right] \right\} \\ &= \text{Re} \left\{ A e^{j(\omega_c t + \phi_1)} a(t) e^{j\theta(t)} \right\} \end{aligned} \quad (2)$$

where $a(t)$ is the amplitude modulation and $\theta(t)$ is the phase modulation[13]. Clearly,

$$a(t) e^{j\theta(t)} = 1 + \rho e^{j(\omega_\Delta t + \phi_2 - \phi_1)}, \quad (3)$$

hence,

$$\ln a(t) + j\theta(t) = \ln \left[1 + \rho e^{j(\omega_\Delta t + \phi_2 - \phi_1)} \right]. \quad (4)$$

Since $\ln(1+z) = \sum_{k=1}^{\infty} (-1)^{k+1} \frac{z^k}{k}$ for $|z| < 1$, the phase modulation can be written as:

$$\theta(t) = \text{Im} \left\{ \ln \left[1 + \rho e^{j(\omega_\Delta t + \phi_2 - \phi_1)} \right] \right\} = \sum_{k=1}^{\infty} \frac{(-1)^{k+1}}{k} \rho^k \sin[k(\omega_\Delta t + \phi_2 - \phi_1)]. \quad (5)$$

The discriminator output voltage is

$$v(t) = \alpha \frac{d\theta(t)}{dt} = \alpha \omega_\Delta \sum_{k=1}^{\infty} (-1)^{k+1} \rho^k \cos[k(\omega_\Delta t + \phi_2 - \phi_1)] \quad (6)$$

where α is a constant which depends on the discriminator circuitry and A .

The discriminator output therefore consists of tones at the difference frequency ω_Δ and its harmonics. The power (into 1 Ω) associated with the k^{th} harmonic is:

$$P_k = \alpha^2 \omega_\Delta^2 \frac{\rho^{2k}}{2}. \quad (7)$$

That is, the power at the discriminator output varies as the square of the frequency offset, all other factors being constant.

2.8.2 Intersil Analysis Includes Non-Linear Effect of Limiter

CUBE Reply Comments, page A2-2:

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"The next major problem with the Intersil FM demodulator analysis is that key non-linear effects have been ignored. The relevant issue is not analysis in additive band-limited white noise, but the case of two interfering signals. Consider the case of two sinusoids given in Figure A2-1, which would represent two carriers. If we let one phasor be A (the desired signal) and the other B (the interfering signal), then the resultant phasor can be called C. For sinusoid, the resultant phasor can be described as a hypocycloid, which is the general class of functions seen in the "Spirograph" toy. The threshold effect results when the signal levels become comparable. The effect of a limiter is to allow only observation of the resultant phasor only when it passes through the real axis. Classical textbook analysis assumes the limited signal is passed immediately through a bandpass filter, which converts the signal back into a rotating phasor, but with significant distortion due to the non-limiting operation. The final operations are a discrimination function, in which frequency is converted to voltage, followed by a final low-pass filtering operation."

Response:

The Intersil analysis did not ignore the effects of the limiter. The presence of a limiter amplifier in the receiver model was clearly shown in Figure 3.3.1 in the Intersil analysis of the effects of overlapping WBFH channels [1]. That figure is reproduced as Figure 2.8.2-1 below.

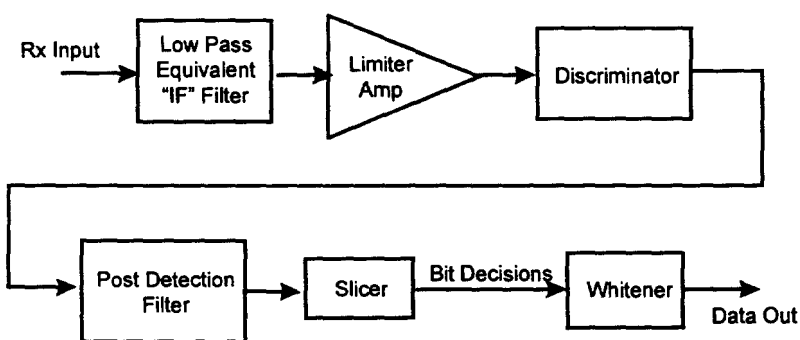


Figure 2.8.2-1 Block Diagram of Intersil Baseband Receiver Model

The Intersil analysis was by no means restricted to the analysis of the performance of an FHSS receiver in white noise. Instead, the Intersil analysis showed the effects of a range of signals, including interference from both conventional narrowband FHSS systems and the proposed WBFH systems.

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The diagram shown in Figure A2-1 of the CUBE comments (the diagram is referred to as Fig. A2-1 in the CUBE text, but is labeled Fig. 5-1) is very similar to Figure 3.3.1 of the Intersil analysis [1] (shown as Figure 2.8.2-1 of this submission). WECA agrees that, prior to the limiter, the signal and interference vectors are combined in a linear manner. This will result in a phase trajectory which is very similar to that of curves generated by a Spirograph toy, as pointed out by CUBE. This effect is entirely consistent with the results presented by Intersil.

Further, the Intersil analysis effectively models “capture effect”. Although difficult to treat via closed form analysis, the effect is accurately modeled via numerical simulation. In the Intersil simulation, signal (S), interference (I), and noise (N) vectors were combined in a linear manner to form a composite received vector (R). The limiter function was simulated by retaining the instantaneous phase of the composite receive vectors (R), and setting the amplitudes of each successive receive vector (R) to the same level. Finally, the discriminator function was accomplished by phase comparison of successive received vectors to compute instantaneous frequency.

Based on this description, it should be clear that the discriminator used in the Intersil simulations did not suffer the distortion effects induced by filtering a limiter output signal. Further, simulation of non-linear received effects via equivalent complex baseband models is a well established technique. The limiter induces a non-linearity into the receiver chain. It therefore becomes impossible to satisfy the Nyquist criteria. As a result, accurate approximation of instantaneous frequency based on the real portion of the limiter output would require an extremely high sample rate. In that event, the simulation would be much slower and less accurate than one which employed an equivalent complex representation of the limiter effects.

2.8.3 Estimated Interference Suppression Conflicts with CUBE Test Data

CUBE Reply Comments, page A2-4:

“Furthermore, the limiter tends to suppress all but the largest signal when one signal is significantly larger than all others: thus, for SIR > 10 dB or so, the interfering signal causes some jitter in the zero crossing information, but generally is of little consequence. In this regard, there is an error in the Intersil simulation as described separately here.”

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Response:

The Intersil analysis indicates that discriminator output errors resulting from SIR values of 10 dB can be quite significant. This is clearly evidenced by CUBE's own test data. From Table 1 of the CUBE reply comments, it can be seen that the OpenAir receiver requires 18 dB SIR against a WBFH interferer, 14 to 15 dB against a NBFH interferer, and 11 to 15 dB against a CW jammer. At no point does CUBE's own test data indicate that the existing FHSS radio they tested can tolerate interference as low as 10 dB SIR for a channel offset of less than 2 MHz.

2.8.4 Intersil Results are Based on Measurements, Simulations, and Analysis

Comments of CUBE, page A2-4:

"It simply not accurate to assume a textbook analysis, especially when actual measurements can be made using practical circuits."

Response

The Intersil analysis of overlapping channels [1] was not based exclusively on simulation or analysis. The measured Aironet receiver desensitization data clearly shows the dependence of receiver performance on interference offset frequency. The CUBE data also supports the Intersil analysis. If, as the proponents claim, the effect of frequency offset is so overstated, how can they explain the fact that the OpenAir radio is 3 to 4 dB more sensitive to a CW jammer located in the adjacent channel relative to a CW jammer located directly in the center of the receiver passband? As we have seen, the OpenAir radio is more sensitive to adjacent channel interference, in spite of IF filter rolloff.

The Intersil simulations are in excellent agreement with the Aironet receiver desensitization data, and have been independently confirmed [16]. The differences between the Intersil results and the CUBE measured data are due to a combination of two factors:

- 1.) The OpenAir radio uses a very wide IF filter
- 2.) In several instances, CUBE made fundamental misinterpretations of their own data, as described more fully below.

2.8.5 CUBE Misapplied Rappaport's Reference to GMSK

CUBE Reply Comments, page A2-5:

"Thus, a WBFH signal could employ GFSK with $BT=0.2$ and increase the modulation index to approximately $h=0.2$ while still meeting the -20 dB channel specification. In fact, GFSK with appropriate h offers BER performance within 1 dB of optimum MSK when $BT = 0.25$."

Response:

The statement above is extremely misleading. It is based on a serious misrepresentation of the cited reference material. On page 264 of Rapport [9]:

"The bit error rate for GMSK was first found by [MUR81] for AWGN channels, and was shown to offer performance within 1 dB of optimum MSK when $BT = 0.25$."

For GMSK systems, the modulation index is *defined* as 0.5. Rappaport is not making reference to varying modulation index. Instead, a review of the reference clearly indicates that the author is discussing the effect of varying the effective filter bandwidth (BT) for GMSK systems.

A system with a modulation index of 0.2 and an effective filter band width of $BT = 0.2$ will require a very high SNR for reliable demodulation, even at the 5 Mbps data rate. It will be far less efficient than the 2 FSK waveform used by both Bluetooth and IEEE 802.11, which has a modulation index of $h = 0.32$, and a Gaussian baseband filter width of $BT = 0.5$. It will not even come close to approaching the performance of optimum MSK.

2.8.6 PSDs of Tested and Simulated Systems are Triangular

CUBE Reply Comments, page A2-6:

"The Intersil paper assumes that the WBFH spectrum is triangular, which is incorrect. In fact, GFSK systems have a parabolic shape in decibels, not triangular. Thus, the spectral shape in the Intersil paper is too high toward the edge of the channel bandwidth, which serves to over exaggerate greatly the partially overlapping interference phenomenon."

Response:

The PSD of a GFSK system depends on the modulation index (h) and the effective baseband filter width (BT). For the systems analyzed by Intersil, the PSDs are triangular. The Intersil representation of a triangular PSD was based on measured data and simulation results which showed the PSD for the systems analyzed as being triangular. A measured PSD plot for an IEEE 802.11 FHSS 2FSK radio ($h = 0.32$, $BT = 0.5$) is shown in Figure 2.8.6-1, and a measured PSD for an 802.11 4FSK radio ($h=0.15$, $BT = 0.5$) is shown in Figure 2.8.6-2.

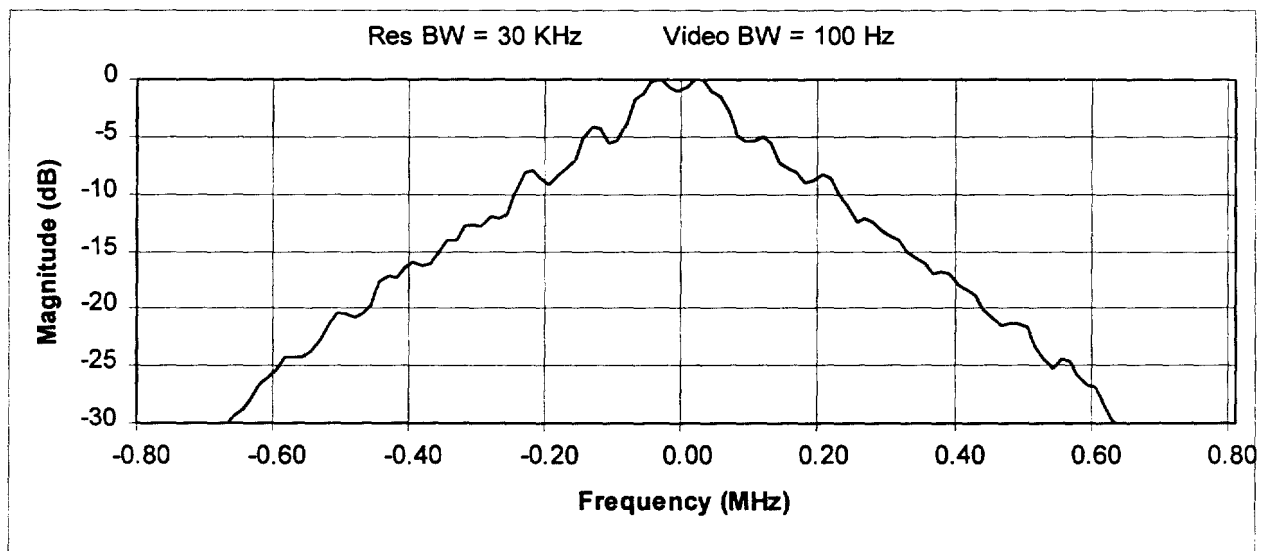


Figure 2.8.6-1 Measured PSD for Aironet 2FSK IEEE 802.11 Compliant FHSS Radio

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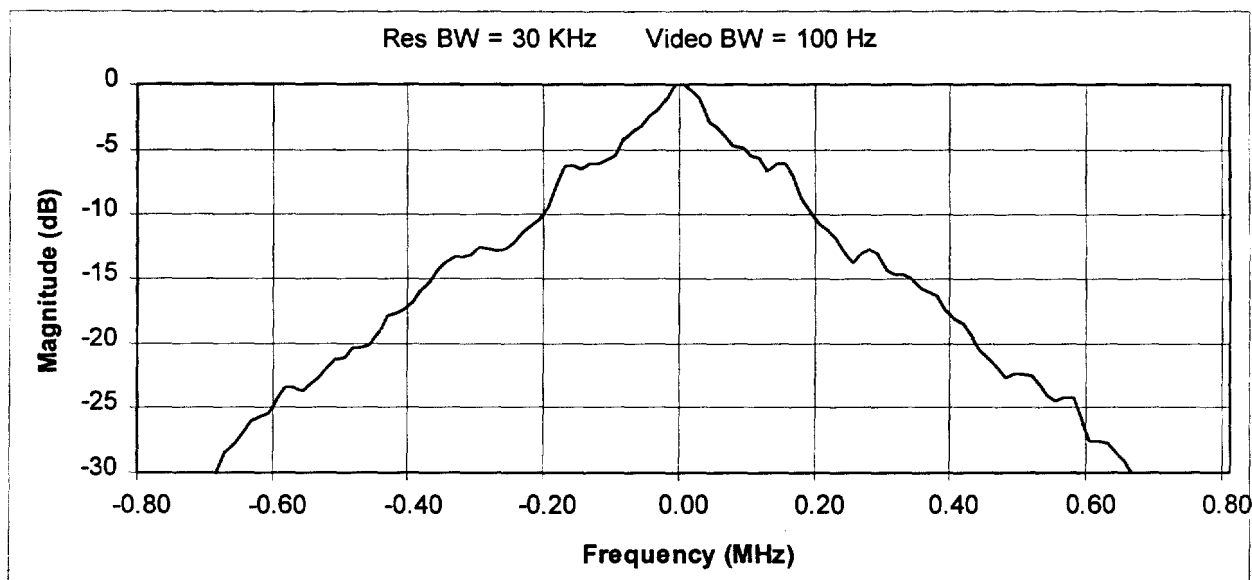


Figure 2.8.6-2 Measured PSD for Aironet 4FSK IEEE 802.11 Compliant FHSS Radio

Finally, the CUBE test data clearly indicates a triangular PSD for the WBFH device they tested. In Figure A2-4 of the CUBE Reply Comments, the plotted PSD for the WBFH device is, in fact, triangular.

2.8.7 CUBE Misrepresents Intersil Simulations

CUBE Reply Comments, page A2-6:

“As mentioned above, the non-coherent FSK receiver described in the Intersil comments has a serious error in the model that dramatically affects the results. It shows two received signals of different amplitudes that are limited separately, then phase compared. This is clearly a serious mistake – the two signals are additive in the IF passband and shown in Figure A2-1, so the time of zero crossing can only be observed for the resultant signal. This dramatically overestimates the impact of interference on the desired signal, and renders the results of the simulation useless.”

Response:

The above statement is incorrect. The Intersil model [1] does include linear addition of the desired signal, interfering signal and noise in the passband before the limiter. This fact is

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clearly demonstrated in Section 3.2 of the Intersil analysis. That section describes the channel model used. An excerpt from that section appears below:

'In this case, the channel model is simply a means of linearly combining the desired signal, an interfering signal, and additive white Gaussian noise (AWGN), or some subset of these signals.'

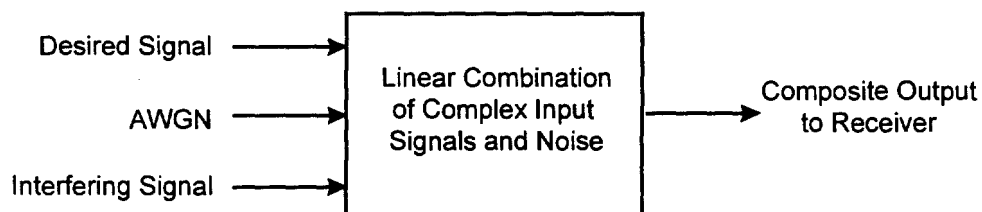


Figure 3.2-1 Simplified Channel Model

Again, a vector representation is a useful means of visualizing the process of linear combination of signals. Linear combination of a desired signal (S), interference (I), and noise (n) is depicted in Figure 3.2.2. Simulation results showing the PSD of a composite signal (C) are shown in Figure 3.2-3.

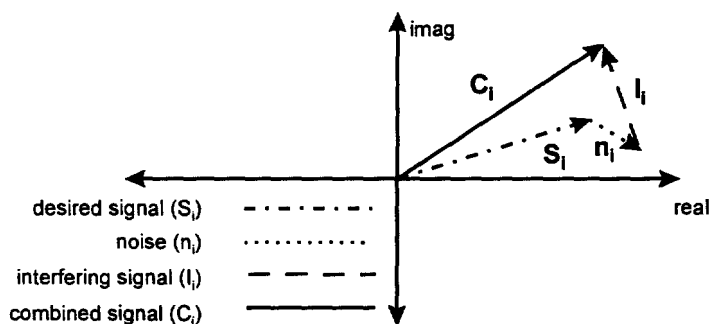


Figure 3.2-2 Linear Combination of Signal, Interference, and Noise

2.8.8 CUBE Signal Trajectory is Incorrect

CUBE Reply Comments, page A2-6:

"The correct signal trajectory is shown in Figure A2-2 below. Note that the limiting operation indicates the zero crossings, so the interference can only jitter this zero crossing information. No matter what the interference type, as SIR drops below the capture ratio, the ability to recover the modulation will be impaired. Likewise, as SIR increases above the capture ratio, the zero crossing jitter will result in only minor impact on the ability to recover the desired signal."

Response:

The trajectory shown in Figure A2-2 of the CUBE analysis is incorrect. The author improperly performed the linear addition of the two signals using power. Vector addition of the desired and interfering signals must be done using voltage, not power. Note that when the correct conversion from decibels to voltage is applied, the envelope of the composite received signal (prior to the limiter amp) has an envelope from 0.68 to 1.32 relative to the desired signal, as shown in Figure 2.8.8-1 below.

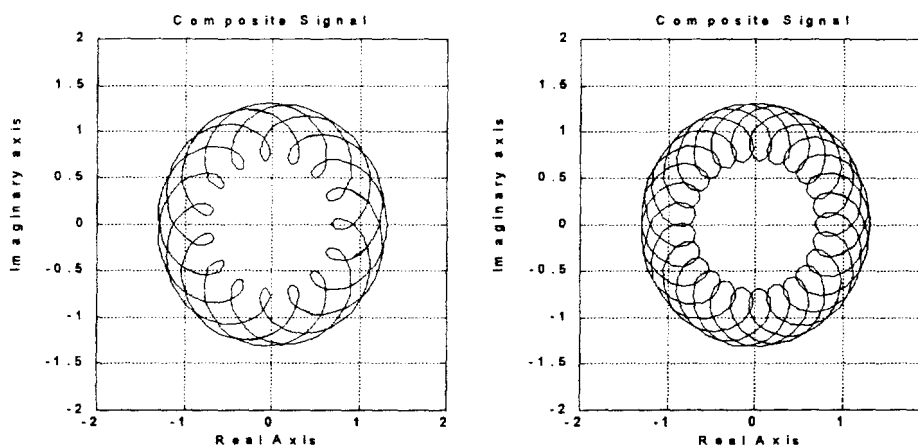


Figure 2.8.8-1 Correct Phase Trajectory for Two Different Offset Frequencies (SIR = 10 dB)

Contrary to CUBE's assertions, for SIR = 10 dB, the effects of interference cannot be ignored. Since the interfering signal is not random noise, but rather is a modulated FSK signal, the result is not a "jitter" in the frequency of the composite received signal, but rather a continuous and predictable slewing of the instantaneous received signal frequency.

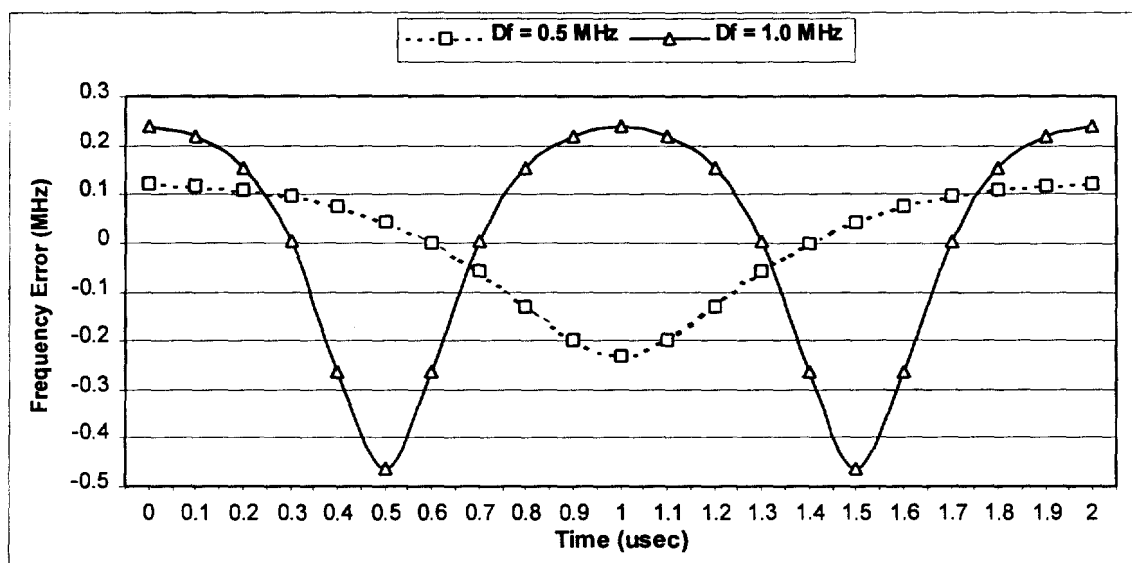


Figure 2.8.8-2 Frequency Error for $\Delta f = 0.5$ MHz and $\Delta f = 1.0$ MHz (SIR = 10 dB)

The curves shown in Figure 2.8.8-2 show the resulting impact on frequency error for two different frequency offsets, 0.5 MHz and 1.0 MHz, with SIR = 10 dB. Note that the curve corresponding to $\Delta f = 1.0$ MHz indicates the frequency error is significantly larger, even though the SIR is the same in both cases. In this example, the increased frequency error is due entirely to the increase in frequency offset.

The fact that many discriminators used in practice are based on detection of the zero-crossing information in no way invalidates the Intersil analysis. Zero crossings contain the instantaneous frequency information, as does phase comparison of consecutive composite received signal vectors, as in the Intersil model. The limiting method used in the Intersil simulation removes the effects of amplitude variations in the received signal, and preserves phase information.

The use of equivalent complex baseband representations as a means of analyzing receiver dynamics, which include non-linear effects such as limiters, is a well-accepted method. It is used in this instance primarily to facilitate computer simulation of the effects under investigation. More specifically, a limiter is a non-linear device. This complicates computer analysis, since there is essentially no way to satisfy the Nyquist criteria. Accurate approximation of the instantaneous frequency of the received signal frequency would require an extremely high

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sampling rate. This issue is largely overcome by the use of the complex baseband representation as described in the Intersil submission to OET [1].

2.8.9 Intersil WBFH Simulations Agree with Measured Results

CUBE Reply Comments, page A2-7:

"In summary, the analytical models used by the opponents for limiter/discriminator behavior are so inaccurate that any conclusions drawn from the model are completely irrelevant. Since the main purpose of the exercise was to consider WBFH interference on legacy FH systems, the sound engineering approach is to focus on actual measurements for systems that already exist."

Response:

The sound engineering approach is to examine empirical results, model the system, and where possible, perform closed form mathematical analysis to demonstrate that the issue under investigation is thoroughly understood. The Intersil analysis accurately models the behavior of an IEEE 802.11 FHSS receiver, based on the measured Aironet test data. Further, a Bluetooth receiver was modeled by making appropriate changes to the channel filter characteristics.

As mentioned previously, the discrepancies between the Intersil results and the CUBE results are explained mostly by the fact that the OpenAir receiver uses a very wide IF filter. Once this factor is taken into account, it can be seen that the CUBE data actually exhibits the same characteristic susceptibility to narrowband interference from offset frequencies as predicted by the Intersil simulations.

The OpenAir receiver used in the CUBE testing has no ACI rejection to speak of. The ACI performance of the OpenAir receiver is 15 dB worse than the minimum ACI performance required for a Bluetooth device. Note that CUBE's own test data in Table 1 of its reply comments clearly indicates that, with a CW interference source, the OpenAir receiver is 3 to 4 dB MORE susceptible to adjacent channel interference compared to co-channel interference.

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Any questions on the accuracy of the Intersil analysis could be dispelled by performing interference tests with the WBFH system as the target. CUBE has failed to perform such tests because the results will confirm that WBFH radios will be extremely susceptible to interference, both from other WBFH systems and from conventional NBFH radios.

2.8.10 CUBE Assessment of WBFH Impact on DSSS is Wrong

CUBE Reply Comments, page A2-8:

“In this section, we will show that direct sequence systems which clearly meet the processing gain requirements of Section 15.247 will also be able to withstand a WBFH signal even when the WBFH signal is received at approximately the same power level. The results show that WBFH and existing FH interfering signals have nearly identical effects, and thus the opponents claims are unfounded.”

Response:

CUBE's assessment of the impact of WBFH interference on DSSS receivers is completely wrong. It is based on a failure to correctly interpret the relative power in the PSD's of WBFH and DSSS signals, as described in the subsequent section. We will show below that CUBE has grossly understated the SIR ratio used in the simulation described in Section B of Appendix 2. Further, this error has been repeatedly used as the basis for CUBE's inaccurate statements regarding the level of interference inflicted on a DSSS receiver by WBFH interference.

2.8.11 CUBE Drastically Misstates DSSS/WBFH SIR

Cube Reply Comments, page A2-9:

“A particularly severe case is when the received signal power for the 802.11 DS is the same as the WBFH interference (SIR=0 dB). In this case, the signal appearing in the DS receiver passband will reflect both signals, as shown in Figure A2-4; note that we have assumed that noise in the passband is negligible for simplicity, since we are only interested in interference effects here.”

Response:

CUBE has understated the SIR of the two signals shown in Figure A2-4 by >10 dB.

Although the peaks of the Power Spectral Densities of the two signals are at the same level, CUBE has failed to take into account the fact that the DSSS signal is MUCH wider. Total signal power is not determined by the peak of the PSD, but rather by integrating the PSD as a function of frequency. As a result of this oversight, CUBE has understated the SIR by 10 dB or more.

Aside from the misstatement of SIR, the severity of the scenario depicted in Figure A2-4 of the CUBE Reply Comments is mitigated by a second factor. The interference shown is offset from the center of the DSSS signal by approximately 7 MHz. The correlation process in the DSSS receiver results in a convolution of the spreading function with the PSD of the interfering signal. As a result of this convolution, interference which is offset from the center of the DSSS passband by 7 MHz is suppressed by approximately 6 dB in addition to the processing gain of 10.4 dB, as shown in Figure 2.8.11-1. Therefore, the SIR in the post correlation filter BW is 10 to 17 dB lower than reported by CUBE.

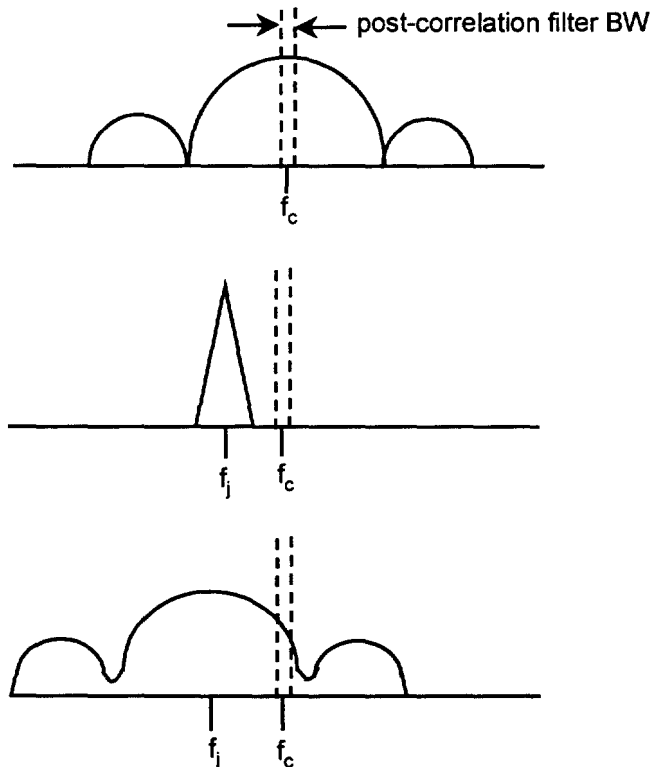


Figure 2.8.11-1 Frequency Offset of Jammer Affects Post Correlation Interference Level

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The aforementioned interference suppression due to the interference offset from band center (in the case of a DSSS receiver) is in addition to the effects of processing gain. The processing gain effect results in a suppression of the WBFH interference by a further 10 dB. Therefore, the post correlation SIR is on the order of 20 to 27 dB! It should come as absolutely no surprise that the DSSS radio is capable of reliable operation with a post-correlation SIR of 20 to 27 dB. CUBE's entire discussion of the performance of a DSSS receiver in the presence of WBFH interference is completely inaccurate and should be disregarded.

2.8.12 CUBE Discussion of Processing Gain is Wrong

CUBE Reply Comments, page A2-10:

"Figure A2-5 shows the 5 MHz signal will be spread out to a signal that is approximately 32 MHz wide before entering the post-correlation filter (5+22+5). If we assume the filter is 2 MHz wide, then the WBFH signal is attenuated by a factor of 16 (12 dB) at the filter output. This is an interesting phenomenon: the DS system actually gets an apparent additional processing gain because the interference is neither very narrowband nor very broadband. Since the DS system has 10.4 dB of processing gain to begin with, we would expect it to perform well in this SIR=0 dB case, and indeed it does"

Response:

CUBE's assessment of the effect of WBFH on DSSS receiver performance is completely wrong. It is based on a misunderstanding of the effects of the matched filter correlation process on uncorrelated signals, which include both WBFH and NBFH interference. CUBE's assertion that WBFH signals result in a post-correlation processing gain is based on a comparison of the post-correlation bandwidth of the interference signal to the bandwidth of the post correlation filter itself.

In fact, WBFH interference results in almost exactly the same level of interference energy falling within the post-correlation filter bandwidth as a narrowband FH interferor of equal energy. Contrary to the incredible claim of a 1.6 dB improvement in processing gain as stated by CUBE, it can be shown that the interference resulting from WBFH and NBFH interferors differs by less than 0.1 dB.

As stated by Ziemer and Peterson [15]: *"The PSD due to the jammer at the despreader output is the convolution of the jammer PSD and the despreading waveform PSD."* In order to

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accurately estimate the relative effect of NBFH interference to that of WBFH interference, the PSD corresponding to each signal type at equal power level was convolved with the spreading function in the frequency domain. The result (on a decibel scale) is shown in Figure 2.8.12-2.

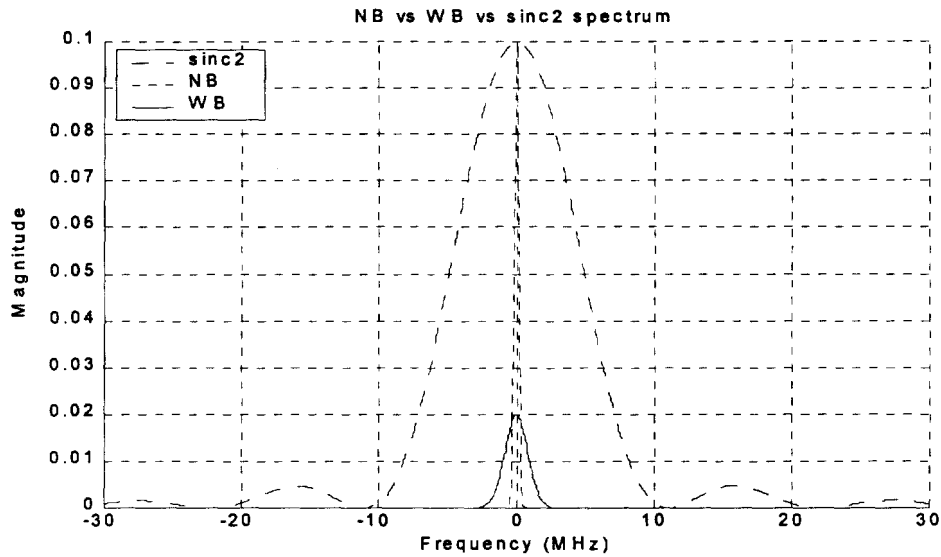


Figure 2.8.12-1 PSD of Equal Power WBFH and NBFH Jammers and Spreading Function

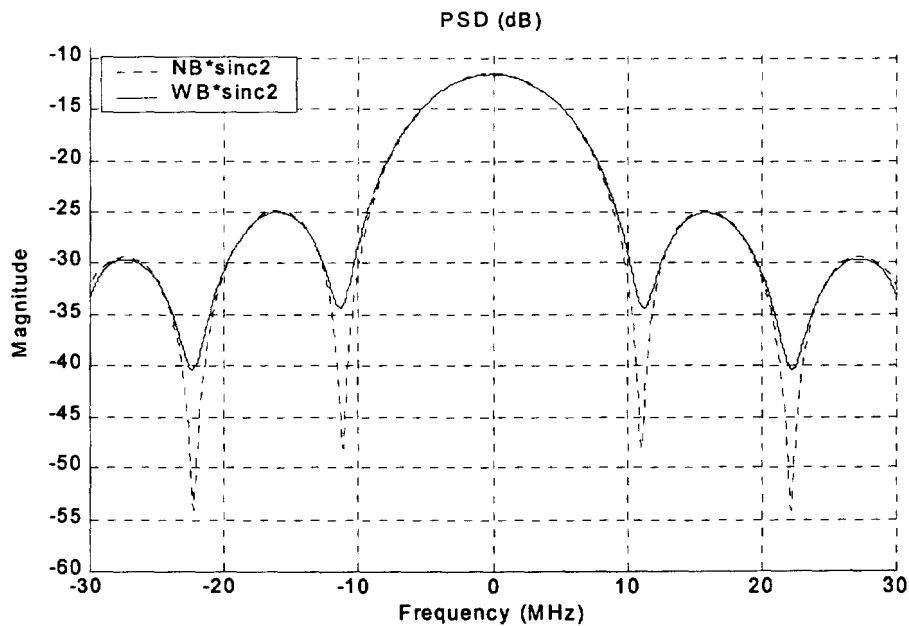


Figure 2.8.12-2 Post Correlation PSD of WBFH and NBFH Jammers (Same Power)

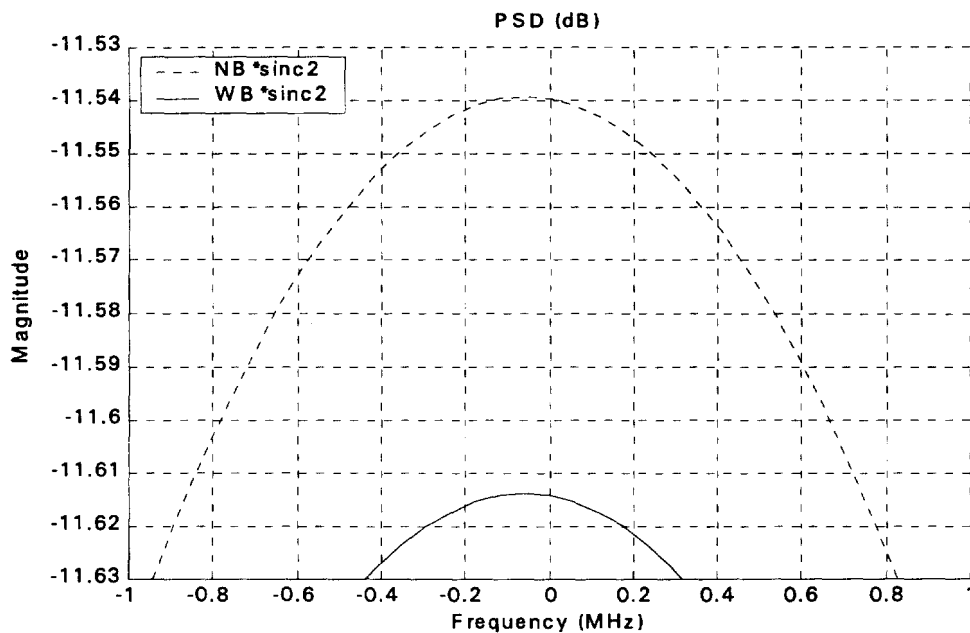


Figure 2.8.12-3 Post-Correlation Noise Densities for NBFH and WBFH Interferers Vary by Less than 0.2 dB

Note that the resulting post correlation noise densities are virtually indistinguishable in the region of the post correlation filter ($-1 \text{ MHz} < f < 1 \text{ MHz}$). When this region of the plot is expanded as shown in Figure 2.8.12-3, it becomes apparent that the noise densities of the spread WBFH and NBFH signals are actually within 0.1 dB of each other. This conclusion is validated by CUBE's own test data. Referring to Table A3-2 of the CUBE Reply Comments, it can be seen that CW, NBFH, and WBFH interference at a given level have exactly the same impact on DSSS operation. CUBE's assertion that WBFH results in a 1.6 dB improvement in processing gain is therefore inaccurate.

It must also be pointed out that the relative degree of interference suppression of WBFH vs NBFH signals is dependent on the location of the interference within the DSSS passband. Referring to Figure 2.8.12-2, the WBFH signal is suppressed by 0.1 dB more than NBFH when the interferors are located at the center of the DSSS passband. However, this situation reverses itself for interference which is located more than 5 to 6 MHz from the center of the DSSS passband. Beyond 5 MHz, the DSSS receiver is less effective at suppressing WBFH interference. For interference located 10 to 11 MHz from band center, the DSSS receiver is actually more than 10 dB less effective in terms of suppressing WBFH interference vs. NBFH interference.

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2.8.13 CUBE Misrepresents Findings of IEEE LMSC (Johnson)

CUBE Reply Comments, page A2-10:

“One of the most extensive comments put forth by the opponent’s to the Commission’s WBFH proposal was made by an individual and submitted under the auspices of the IEEE 802.11 Committee. Johnson’s Annex contains many pages of apparently complex mathematical derivations mixed with sometimes correct but often erroneous assumptions, which lead to the false conclusion that WBFH systems need substantially greater power reductions in order to achieve interference neutrality compared with existing systems”.

Response:

The following response is provided by Don Johnson of WLAN Consulting.

CUBE presented their appendix 2C analysis as correcting invalid assumptions in the IEEE LMSC analysis [14]. The CUBE analysis does not have the wide scope of the IEEE LMSC analysis and actually verifies some of the IEEE LMSC assumptions in a particular case.

The CUBE analysis took one conclusion of the IEEE LMSC annex 1 analysis (IEEE LMSC annex 1) which was favorable to their case and further studied it very extensively. Their study actually showed, in extreme detail, that the IEEE LMSC annex 1 analysis was true in a specific circumstance. CUBE verified the one conclusion of the annex 1 analysis under a particular set of operating assumptions with all conditions of traffic loading. No significant assumptions were shown to be invalid and no different conclusions from those of the IEEE LMSC annex 1 analysis were demonstrated.

The IEEE LMSC analysis extensively investigated the effect of WBFH on current spread spectrum frequency hopping and direct sequence packet data systems, with an emphasis on showing the effect of power level on the interference probability. Four conclusions were reached concerning the relative interference increase of WBFH systems over spread spectrum packet data systems operating under the present rules. These are listed here in the order of decreasing relative interference effect:

1. WBFH with fast frequency hopping has such a severe relative effect on legacy frequency hopping packet data systems that an unrealistically large power level difference (much in excess of 20 dB) would be required to equalize it.

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2. WBFH with slow frequency hopping has a severe effect on legacy frequency hopping packet data systems. A power level difference on the order of 20 dB would be required to equalize it.
3. WBFH with fast frequency hopping has a significant relative effect on direct sequence spread spectrum packet data systems. A power level difference on the order of 13 to 15 dB would be required to equalize this.
4. WBFH with slow frequency hopping has nearly negligible relative effect on direct sequence spread spectrum packet data systems.

CUBE chose to elaborate on the last conclusion, the conclusion most favorable to their case, and to ignore the other ones. Conclusion number 4 is verified in Table 4-2 of IEEE LMSC Annex 1. CUBE shows none of the IEEE LMSC annex 1 assumptions to be invalid.

CUBE based their analysis on a slow frequency hopping system (consistent with point 4) and maintains that the systems they provide will employ slow frequency hopping. While this promise of a slow hopping rate for systems provided by the CUBE members is undoubtedly true as currently planned, the proposed regulations do not stipulate it. The plans may change and other systems, some supplied by organizations not members of CUBE, will almost certainly be developed using the new rules. Point 3 above, concerning the effect of the rule change on fast frequency hopping systems, is the relevant conclusion concerning the effect of WBFH on direct sequence packet data systems. This shows a significant interference increase and the proposed limits on the power level do not compensate for it even if the current systems increase their levels to the maximum allowable.

However, more seriously, CUBE chooses to ignore the effect of the increased bandwidth on 1 MHz bandwidth frequency hopping systems. Even slow frequency hopping WBFH systems such as CUBE claims to be planning would very seriously increase interference with these legacy systems.

2.9 CUBE Appendix A3: Measurements

2.9.1 CUBE Test Data Demonstrates Effect of Interference on FM Demodulation

CUBE Reply Comments, Table A3-1:

Offset Frequency from center	Signal to Interference Ratio (dB)				
	CW	802.11 FH	WBFH (as measured)	WBFH (effective)	802.11b 11 Mb.s DS
-5 MHz	< -30	< -30	< -30	< -30	7
-4 MHz	< -30	< -30	-20	-27	8
-3 MHz	-29	< -30	-8	-15	9
-2 MHz	-24	-18	5	-2	10
-1 MHz	14	15	18	11	11
Center (0)	11	14	18	11	12
+1 MHz	15	15	18	11	11
+2 MHz	-17	-11	5	-2	10
+3 MHz	-29	-28	-7	-14	9
+4 MHz	< -30	< -30	-19	-26	9
+5 MHz	< -30	< -30	< -30	< -30	8

Table 2.9.1-1 Measured SIR requirements of an existing FH receiver (CUBE Table A3-1)

Response:

The results shown in Table A3-1 of the CUBE Reply comments verify the analysis of Intersil and Silicon Wave which clearly indicate that FSK receivers are much more susceptible to interference at or near the edge of the passband than co-channel interference which falls at the center of the passband.

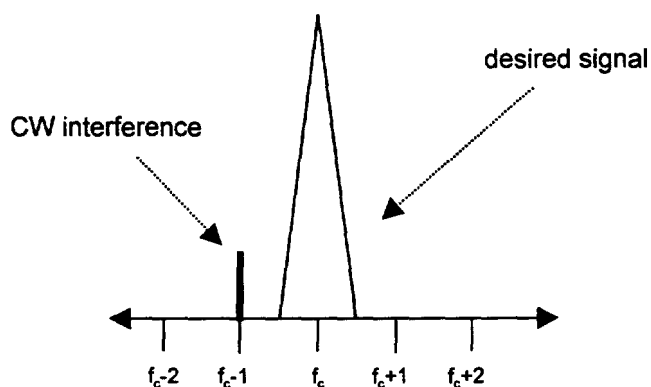


Figure 2.9.1-1 Existing FH Device is More Susceptible to ACI than CCI

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In Table 2.9.1-1, the columns entitled “*CW*” and “*802.11FH*” clearly indicate that the existing FH receiver is more susceptible to interference from a both CW source and from an FHSS transmitter when the interference is located in the adjacent channel (± 1 MHz offset) than to co-channel interference (0 MHz offset). As shown in Figure 2.9.1-1, ACI is centered well outside the FH receiver passband.

The IF filter in the FH receiver is suppressing the interference by several decibels at this point, yet ACI causes more serious degradation than interference which falls directly within the receiver passband. This is entirely consistent with the effect described in the Intersil analysis of the effects of using overlapping FHSS channels [1].

The column entitled “*WBFH (as measured)*” shows the effect of WBFH interference on the existing FH receiver. It must be noted that the WBFH interference source used only had a 3.6 MHz wide bandwidth (see CUBE Reply Comments, Appendix 3, page 14). These results therefore are not representative of the effects of a WBFH interference source which has a full 5 MHz bandwidth. Such an interference source would create higher levels of interference across a wider bandwidth. The Commission should be aware that this data does not correspond to the maximum level of interference that WBFH systems will be capable of inflicting on existing FHSS radios.

The column entitled “*WBFH (effective)*” is misleading and should be ignored by the Commission. The problem with the data shown in this column of Table A3-1 was discussed extensively in Section 2.6.7, but bears repeating here:

The levels shown for “WBFH (effective)” are misleading and should be ignored by the Commission. SIR is defined as the Signal-to-Interference Ratio measured at the receiver input. Changing the transmit power will not alter the performance of the receiver for a given SIR. All other things being equal, lowering the transmitted power from an interference source will increase the SIR at the receiver. It will not result in improved receiver performance at a lower SIR.

Consider the case in which a WBFH transmitter is on the same center channel as an OpenAir network. From the data in Table 1 of the CUBE Reply Comments, the data in the column labeled “WBFH (effective)” indicates that the OpenAir receiver would operate reliably at

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an SIR of >11 dB. This is not the case. An SIR of 18 dB is required at the receiver regardless of the power level of the WBFH transmitter. The issue of maximum allowable transmit power level for the proposed WBFH transmitters is relevant to this proceeding. However, in order to avoid confusion, it should not be combined with a discussion of receiver performance vs. SIR in this manner.

Finally, consider the data shown in the column entitled "802.11b 11 Mb/s DS". As described elsewhere in this report, the OpenAir radio used as a target receiver has poor interference rejection characteristics because of the combination of a wide IF filter, and the effects of interference with large instantaneous frequency offset from the desired signal. Bluetooth receivers are more indicative of the level of interference rejection performance that FHSS systems can achieve if robust IF filtering is employed. It has been estimated that a Bluetooth receiver could withstand much higher levels DS than those stated by CUBE [11].

2.9.2 CUBE Test Data Invalidates CUBE Analysis

CUBE Reply Comments, page A3-8:

"The measured results are summarized below in Table A3-2. It is obvious that WBFH has no significant effect upon IEEE802.11b system performance, other than slightly reduced interference as predicted by the analysis in Appendix 2."

Offset Frequency from center	Signal to Interference Ratio (dB)		
	CW	802.11FH	WBFH (as measured)
-8 MHz	3	2	3
-6 MHz	6	6	6
-4 MHz	8	8	8
-2 MHz	8	8	8
Center (0)	9	9	8
+2 MHz	8	8	8
+4 MHz	8	8	8
+6 MHz	6	7	7
+8 MHz	2	3	3

Table 2.9.2-1 Measured SIR Requirements of an Existing DS Receiver (CUBE Table A3-2)

Response

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Not even the most optimistic interpretation of the results shown in Table A3-2 could be taken as validation of CUBE's claim in Appendix 2 that WBFH interference resulted in a reduction of interference to DSSS systems of 1.6 dB. There is only a single data point (offset frequency of 0 MHz) for which the WBFH is more benign than either CW or 802.11FH interference, which is probably explained by experimental error. CUBE's inaccurate claim of 1.6 dB additional processing gain for DSSS receivers in the presence of WBFH interference should have manifested itself for all frequencies tested. The fact that the 1.6 dB of processing gain failed to materialize in the test data somehow did not prevent CUBE from making erroneous claims regarding the effect of WBFH interference on DSSS systems. As described in Section 2.8.12, CUBE's assessment of the impact of WBFH interference on DSSS receiver performance is not accurate. The interference from WBFH and NBFH systems differ by <0.1 dB for interference located at the center of the DSSS signal. When the interference is located more than 6 MHz from the center of the DSSS passband, WBFH interference is actually worse than NBFH interference.

It is worth mentioning that the concerns of DSSS manufacturers relating to interference are not related to the PSD of WBFH signals per se, but rather to the very high power levels they will be required to operate at to support the applications cited by proponents. As previously mentioned, to operate at the power levels comparable to high rate DSSS systems, WBFH radios will be required to transmit 15 to 20 dB higher power just to perform well in the presence of AWGN. Due to the use of limited front ends, effective channel equalization will be extremely difficult, if not impossible, which will increase packet errors and result in a very high level of retransmission.

2.9.3 CUBE Throughput Measurements are Inconclusive

CUBE Reply Comments, page A8:

"The coexistence potential or interference performance was assessed by comparing the effective throughput performance of each of the "Target" systems in a baseline condition (no interference present) to the effective throughput performance of the same Target system in the presence of multiple independent interference "Sources". The Coexistence potential between the various technologies is indicated by the percentage reduction in throughput from the baseline measurements."

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Response:

The transmit output power levels of the devices used in CUBE's interference tests are summarized in Table 2.9.3-1 below.

Interference Source	Access Point Tx Power (mW)	PC Card Tx Power (mW)
IEEE 802.11 FH	200	200
OpenAir (FH)	500	100
Bluetooth	100	100
IEEE 802.11b (DS)	100	100
WBFH	*****	100

Table 2.9.3-1 Interference Source Transmit Power Levels

The exact test configuration is not clear. Figure A3-4 of the CUBE Reply Comments includes a schematic of the test set up, which is helpful. However, the photograph of Figure A3-5 is obscured. For the purposes of this discussion, it is assumed that the devices are arranged in a line. Therefore, for the case where range (R) is equal to 5 meters, the relative separations of all devices under test are as shown in Figure 2.9.3-1 below.

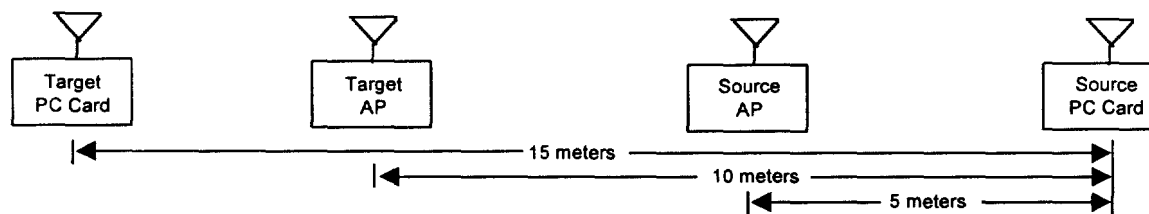


Figure 2.9.1-1 Assumed Arrangement of Devices for CUBE Testing (R = 5m)

Note that there is no WBFH access point defined. The WBFH Source PC Card was a transmitter which was placed at the Source PC Card Location. Therefore, the WBFH interference source was both of lower power and further away from the target devices than either the IEEE 802.11FH or the OpenAir Source Access Points. In addition, the Aironet cards used for the purpose of this test were at the maximum range of their adjustable range for transmit power. The Aironet PC cards are adjustable from 10 to 100 mW. DSSS cards from other vendors such as Lucent operate at 30 mW. Finally, the vast majority of Bluetooth radios will have only 0 dBm transmit power. Therefore, the CUBE test results cannot be considered to be representative of many common deployment scenarios.

It must be reiterated that the concerns of the DS manufacturers are not related to the PSD of the WBFH signal per se, but rather to the degree of compatibility of the to radio technologies.

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The CUBE results do not include test results which indicate how well WBFH radios can tolerate interference from other radio types, which include existing FHSS and DSSS systems. WECA restates its position that WBFH radios will be extremely susceptible to interference from existing systems, and will therefore suffer a high packet error rate. This in turn will result in a high rate of packet retransmission. In addition, as previously stated, WBFH radios will require high power to operate reliably even over very short ranges. Neither situation is conducive to efficient use of the spectrum.

3.0 Conclusions

WECA applauds the decision by CUBE to drop its insistence on a higher mandatory hop rate for WBFH systems. However, WECA reaffirms its opposition to the use of overlapped FHSS channels. Further, the power reductions proposed for WBFH systems are inadequate to prevent other users of the spectrum from harmful levels of interference. In addition, CUBE has made no attempt to validate its claims regarding delivery of data at 6 Mbps in a 3 MHz channel or 10 Mbps in a 5 MHz channel.

The proposal put forward by HomeRF in November of 1998 differed from a previously rejected proposal for WBFH in two ways:

- 1.) The mandatory minimum hop rate was increased for WBFH systems
- 2.) The use of 75 hopping frequencies was retained via the use of overlapping channels

Both measures have now been shown to increase interference to other users. The issue of higher mandatory hop rates has now been resolved, but the use of overlapping channels remains a point of controversy. The analysis of put forward by WECA and its constituents have shown that prohibiting the use of overlapping channels would reduce the rate of collisions among WBFH systems by up to 50%.

CUBE's assertions regarding the performance of DSSS systems in the presence of WBFH interference are based on fundamental technical errors. Although CUBE represented their results as being based on performance at SIR = 0 dB, the plotted PSDs of the two signals involved clearly indicated that the actual SIR was >10 dB. CUBE thereby drastically understated the adverse impact of WBFH on DSSS systems. In addition, CUBE's analysis of the noise

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suppression characteristics of DSSS receivers in the presence of WBFH noise is completely wrong.

Finally, in spite of the claims of proponents of WBFH, the proposed rule changes are not consistent with ETSI regulations, and do not promote global harmonization of spectrum sharing rules. Based on these considerations, WECA urges the Commission to reject the proposed rule changes which would permit operation of WBFH devices in the 2.4 GHz ISM band.

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